Inclusion of fiber in diets for brown-egg laying pullets: Effects on growth performance and digestive tract traits from hatching to 17 weeks of age[1]

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ABSTRACT We investigated the effects of fiber inclusion in the diet on growth performance and digestive traits in pullets from hatching to 17 wk of age. The control diets of the 3 feeding periods (0 to 5 wk, 5 to 10 wk, and 10 to 17 wk) were based on corn and soybean meal and did not include any additional fiber source. The experimental diets included 2 or 4% of cereal straw or sugar beet pulp (SBP) at the expense (wt:wt) of the control diet. From 0 to 5 wk of age, fiber inclusion did not affect pullet performance. From hatch to 17 wk of age, the inclusion of straw had little effect on pullet performance but the inclusion of 4% SBP reduced (ADG) ($P < 0.05$) and reduced feed conversion ratio (FCR; $P < 0.001$). Pullets fed straw had greater ADG ($P < 0.05$) and better energy conversion ratio ($P < 0.01$) than pullets fed SBP. An increase in fiber from 2 to 4% reduced FCR ($P < 0.05$). Body weight uniformity was not affected by diet. Fiber inclusion increased the relative weight (% BW) of the gizzard at 5 wk ($P = 0.056$) and 10 wk ($P < 0.01$) of age, but no differences were detected between fiber sources. At same ages, the relative length (cm/kg BW) of the pullets ($P = 0.058$ and $P < 0.01$, respectively) and tarsus ($P = 0.079$ and $P < 0.05$, respectively) was higher in pullets fed SBP than in pullets fed straw. Fiber inclusion, however, did not affect any of these traits at 17 wk of age. In summary, the inclusion of 2% straw at the expense (wt:wt) of the whole diet did not affect pullet performance at 17 wk of age. An increase in the level of straw from 2 to 4% reduced FCR but did not affect ADG. The inclusion of SBP, however, reduced pullet growth, with effects being more pronounced at the higher level.

Key words: cereal straw, gastrointestinal tract, pullets, sugar beet pulp

INTRODUCTION

Traditionally, the inclusion of fiber in poultry diets was limited because of the poor adaptation of the gastrointestinal tract of young birds to fibrous ingredients (Sell 1996; Uni et al., 1999), which affects feed intake, nutrient digestibility, and growth (Janssen and Carré, 1985; Sklan et al., 2003). Recent research, however, has shown that the inclusion in the diet of moderate amounts of certain insoluble fiber sources might improve gastrointestinal function and maximize growth performance in broilers (Jiménez-Moreno et al., 2009a; Svihus, 2011; Incharoen, 2013) and pullets (Guzmán et al., 2015) during the first stage of life. Numerous ingredients, including oat hulls (**OH**), sunflower hulls (**SFH**), pea hulls, rice hulls, soy hulls, and sugar beet pulp (**SBP**), have been tested as a source of additional fiber in poultry diets (González-Alvarado, 2010; Kalmendal et al., 2011; Jiménez-Moreno et al., 2011, 2013a). Straw is an insoluble fiber source of uniform quality, but the information available on its use as a dietary component in poultry diets is scarce. In fact, no research is available on the effects of straw on growth performance and gastrointestinal tract development of pullets from hatching to 17 wk of age. On the other hand, SBP, a soluble fiber source, has been largely studied as a source of dietary fiber in broilers (Pettersson and Razdan, 1993; Jiménez-Moreno et al., 2009b) but little information is available in pullets. Most papers that compared the effects of fiber in broilers reported greater benefits with the inclusion of insoluble sources than with the inclusion of soluble sources (González-Alvarado et al., 2010; Jiménez-Moreno et al., 2013a). Insoluble fiber stimulates more the development of the upper part of the gastrointestinal tract (**GIT**) than soluble fiber (González-Alvarado et al., 2008), which, in turn, improves the development and facilitates the adaptation of the digestive tract of the birds to consume more feed. However, no information is available comparing insoluble and soluble fiber sources in diets for pullets from hatch to 17 wk of age.

The hypothesis of this research was that the inclusion in the diet of adequate amounts of an insoluble fiber source, but not of a soluble fiber source, could improve gastrointestinal tract function and pullet performance. The aim of this research was to evaluate the inclusion in the diet of 2 fiber sources varying in physicochemical characteristics at 2 levels—performance and gastrointestinal tract development—of brown-egg laying pullets from hatching to 17 wk of age.

MATERIALS AND METHODS

Husbandry

The experimental procedures used in this research were approved by the Animal Ethics Committee of Universidad Politécnica de Madrid and were in compliance with the Spanish guidelines for the care and use of animals in research (Boletín Oficial Estado, 2007).

In total, 2,500 one-day-old (37.1 ± 1.31 g) Lohmann Brown Classic pullets were housed in an environmentally controlled barn and randomly allotted in groups of 50 to 50 cages (40 cm × 80 cm × 68 cm; Facco, Padova, Italy) provided with an open trough feeder and 2 low pressure nipple drinkers. The average BW of the pullets was similar for all cages. Because of the equipment and dimensions of the cages, only 22 pullets chosen at random formed the experimental unit after 3 wk of age. Pullets were beak-trimmed at the hatchery and kept on a 22 h/d light program for the first week of life. The light was decreased gradually until reaching 10 h/d at 10 wk, kept constant from 10 to 15 wk of age and then, increased gradually to 13 h/d to the end of the experiment. Barn temperature was maintained at 32 ± 1.5°C for the first 3 d of life and reduced gradually until reaching 20°C at 6 wk. From 6 to 17 wk, the temperature of the barn varied between 22 and 25°C depending on weather conditions. Pullets were vaccinated against main diseases (Infectious Bronchitis Disease, Marek Disease, Infectious Bursal Disease, Newcastle Disease, and *Salmonella* spp.) and managed according to accepted commercial practices (Lohmann, 2013).

Table 1. Chemical analyses (% as fed basis, unless otherwise indicated) and physicochemical characteristics of the fiber sources.

Fiber source	Straw	Sugar beet pulp
Calculated chemical analysis[1]		
AME$_n$ (kcal/kg)	200	900
Ether extract	1.6	0.8
Crude fiber	36.0	18.2
Determined chemical analysis		
DM	91.3	92.0
Gross energy (kcal/kg)	3,854	3,729
CP	2.8	9.2
Total ash	6.7	5.6
Neutral detergent fiber	69.9	31.7
Acid detergent fiber	41.5	15.6
Acid detergent lignin	5.6	1.7
Total dietary fiber	78.5	64.7
Soluble dietary fiber	3.8	10.6
Insoluble dietary fiber	74.7	54.1
Physical properties		
Particle size[2] (μm)		
2,500	0.2	1.2
1,250	12.3	33.5
630	40.4	35.2
315	28.4	18.4
160	15.3	9.0
80	2.9	2.3
GMD[3] ± GSD[4]	602 ± 2.01	835 ± 2.12
WHC[5] ± SD	7.5 ± 0.14	8.7 ± 0.27
SWC[6] ± SD	3.6 ± 0.23	6.6 ± 0.56
Buffer properties		
Initial pH[7]	8.39 ± 0.052	5.62 ± 0.033
Base-buffering capacity[8]	–	50.9 ± 5.6
Acid-buffering capacity[9]	134.2 ± 10.2	96.3 ± 5.2

[1]According to Fundación Española para el Desarrollo de la Nutrición Animal (2010).

[2]The percentage of particles bigger than 2,500 μm or smaller than 80 μm were negligible for all diets.

[3]Geometric mean diameter (μm).

[4]GSD = Log normal SD.

[5]Water holding capacity (mL/g DM).

[6]Swelling capacity (mL/g DM).

[7]pH of 10 g DM of the fiber source suspended in 200 mL double distilled water.

[8]μEq of NaOH required to increase the pH of 10 g DM of the fiber source suspended in 200 mL double distilled water from the initial pH to pH 7 divided by pH change. The base-buffereing capacity of the straw could not be measured because the initial pH was above 7.00.

[9]μEq of HCl required to decrease the pH of 10 g DM of the fiber source suspended in 200 mL double distilled water from pH 7 to pH 4 divided by pH change.

Fiber Sources, Diets, and Experimental Design

Batches of straw and SBP were received as 9-mm pellets from a trader. The straw used was a mixture of 80% wheat and 20% barley straw, and was processed with 2% sodium hydroxide solution before pelleting. Both fiber sources were ground using a hammer mill fitted with a 4-mm screen before being included in the corresponding experimental diets. The chemical analyses and the physical characteristics of the 2 fiber sources are shown in Table 1.

The feeding program consisted of 3 phases: starter (0 to 5 wk), grower (5 to 10 wk), and developer (10 to 17 wk), and the control diets used were based on corn and soybean meal. For the manufacturing of these diets, the ingredients were ground with a hammer mill fitted with a 2-mm (starter period) or a 3-mm (grower and developer periods) screen. The remaining experimental diets resulted from the inclusion of 2 or 4% straw or SBP at the expense (wt:wt) of the whole control diets. Diets were mixed using a horizontal ribbon mixer (Mecafa S.A., Ciudad Real, Spain). All diets met or exceeded the nutritional requirements of pullets as recommended by the Fundación Española Desarrollo Nutrición Animal (2008), but the diets that included a fiber source had more crude fiber and slightly less AME$_n$ and CP than the control diets. All diets included a commercial enzyme complex with xylanase and β-glucanase activity

Table 2. Ingredient composition (% as fed basis) of the experimental diets.

	0 to 5 week			5 to 10 week			10 to 17 week		
		Fiber diets			Fiber diets			Fiber diets	
	Control diet	2%	4%	Control diet	2%	4%	Control diet	2%	4%
Barley	–	–	–	5.0	4.9	4.8	26.0	25.5	25.0
Corn	40.0	39.3	38.5	40.0	39.2	38.4	40.0	39.2	38.4
Wheat	18.0	17.6	17.3	15.0	14.7	14.4	1.10	1.08	1.06
Soybean meal, 47% CP	35.0	34.3	33.6	25.2	24.7	24.2	18.8	18.4	18.0
Wheat bran	–	–	–	10.1	9.9	9.7	10.2	10.0	9.8
Fiber source[1]	–	2.0	4.0	–	2.0	4.0	–	2.0	4.0
Poultry fat	2.65	2.54	2.44	1.04	1.02	0.98	0.50	0.49	0.48
Dicalcium phosphate	2.05	2.01	1.95	1.35	1.32	1.30	0.96	0.94	0.92
Calcium carbonate	1.26	1.22	1.20	1.28	1.26	1.23	1.50	1.47	1.45
Sodium chloride	0.36	0.35	0.34	0.33	0.32	0.31	0.35	0.34	0.34
DL-Met, 99%	0.18	0.18	0.17	0.16	0.15	0.15	0.08	0.08	0.07
L-Lys HCl, 78%	–	–	–	0.04	0.03	0.03	–	–	–
L-Thr, 98%	–	–	–	–	–	–	0.01	0.01	0.01
Vitamin and mineral premix[2]	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5

[1]The fiber sources used were sugar beet pulp and straw, depending on the experimental treatment.

[2]Provided the following (per kilogram of diet): vitamin A (trans-retinyl acetate), 10,000 IU; vitamin D_3 (cholecalciferol), 3,000 IU; vitamin E (all-*rac*-tocopherol-acetate), 30 mg; vitamin B_1, 2 mg; vitamin B_2, 8 mg; vitamin B_6, 4 mg; vitamin B_{12} (cyanocobalamin), 0.025 mg; vitamin K_3 (bisulphatemenadione complex), 3mg; choline (choline chloride), 250 mg; nicotinic acid, 60 mg; pantothenic acid (D-calcium pantothenate), 15 mg; folic acid, 1.5 mg; betaíne anhydrous, 80 mg; D-biotin, 0.15 mg; zinc (ZnO), 80 mg; manganese (MnO), 70 mg iron ($FeCO_3$), 60 mg; copper ($CuSO_4{\cdot}5H_2O$), 8 mg; iodine (KI), 2 mg; selenium (Na_2SeO_3), 0.2 mg; Roxazyme, 200 mg [1,600 U of endo-1,4-β-glucanase (EC 3.2.1.4), 3,600 U of endo-1,3 (4)-β-glucanase (EC 3.2.1.6), and 5,200 U of endo-1,4-β-xylanase (EC 3.2.1.8)] supplied by DSM S.A., Madrid, Spain; and Natuphos 5000, 60 mg (300 phytase units/kg) supplied by Basf Espanola S.A., Tarragona, Spain.

(Roxazyme, DSM S.A., Madrid, Spain). In the formulation of the diets, it was accepted that the inclusion of the enzyme complex increased the AME_n content of the wheat and barley grains by 2% (from 3,150 to 3,213 kcal/kg for wheat and from 2,800 to 2,856 kcal/kg for barley) but did not affect the energy content of the other ingredients (Fundación Española Desarrollo Nutrición Animal, 2010). Diets were offered for ad libitum consumption in mash form. The ingredient composition of the starter, grower, and developer diets is shown in Table 2 and the calculated and determined chemical analysis, as well as their particle size distribution, are shown in Tables 3, 4, and 5, respectively.

The experimental design was completely randomized with 5 treatments that consisted in a control diet without any additional fiber source and 4 extra diets arranged as a 2 × 2 factorial with 2 fiber sources (straw and SBP) at 2 levels of inclusion (2 and 4%). Each treatment was replicated 10 times and the experimental unit was the cage for all measurements.

Growth Performance

Feed disappearance was recorded by cage and pullets were individually weighed at 5, 10, and 17 wk of age. Feed wastage was not measured. Any mortality was recorded and weighed as produced. From these data, (**ADG**), average daily feed intake (**ADFI**), and feed conversion ratio (**FCR**) were determined by feeding phase and cumulatively. In addition, energy intake (**EI**), expressed as kilocalories of AME_n ingested per day, and energy conversion ratio (**ECR**), expressed as kilocalories of AME_n required per gram of gain, were measured at same ages. Body weight uniformity was determined by replicate as indicated by Peak et al. (2000). Briefly, the CV of the individual BW of the pullets of each cage replicate was generated and this variable was used as an indirect measurement of BW uniformity.

Gastrointestinal Tract Traits and Body Measurements

At 5, 10, and 17 wk of age, after the corresponding productive performance controls, 2 birds per replicate were randomly selected, weighed, and euthanized by CO_2 inhalation. The GIT, from the beginning of the proventriculus to the cloaca, including digesta content, liver, pancreas, and spleen, but not the crop and the esophagus, was removed aseptically and weighed. Then, the liver and the full proventriculus and gizzard, were excised and weighed and expressed relative (%) to live BW. The pH of the gizzard was measured in situ in duplicate at 10 wk of age using a digital pH meter fitted with a fine tip glass electrode (model 507, Crison Instruments S.A., Barcelona, Spain) as indicated by Jimenez-Moreno et al. (2009b). The mean value of the 2 measurements was used for further statistical evaluation. The proventriculus and gizzard were emptied from any digesta, cleaned, dried with desiccant paper, and weighed again, and the fresh digesta content was calculated as the difference between the full and empty organ weights and expressed relative (%) to full organ weight. The length of the duodenum (from the gizzard to the pancreo-biliary ducts), jejunum (from the pancreo-biliary ducts to Meckel's diverticulum), ileum

Table 3. Chemical analyses (% as fed basis, unless otherwise indicated) and particle size distribution of the starter diets (0 to 5 wk of age).

	Control diet[1]	Straw (2%)	Straw (4%)	SBP[2] (2%)	SBP (4%)
Calculated chemical analysis[3]					
AME_n (kcal/kg)	2,960	2,898	2,839	2,914	2,870
Digestible amino acids					
Lys	1.01	0.99	0.97	0.99	0.97
Met	0.47	0.47	0.45	0.47	0.45
Met+cys	0.77	0.76	0.74	0.76	0.74
Thr	0.69	0.68	0.66	0.68	0.67
Trp	0.23	0.22	0.22	0.22	0.22
Ether extract	5.1	5.0	4.8	4.9	4.8
Crude fiber	2.9	3.5	4.1	3.2	3.5
Calcium	1.10	1.08	1.06	1.09	1.09
Phosphorus	0.74	0.73	0.71	0.73	0.71
Digestible phosphorus	0.43	0.42	0.41	0.43	0.42
Determined chemical analysis					
DM	90.4	90.9	91.4	91.1	91.8
Gross energy (kcal/kg)	4,017	4,085	4,048	4,094	4,109
CP	20.8	20.4	20.3	20.7	20.5
Neutral detergent fiber	9.4	10.3	11.4	9.7	10.0
Acid detergent fiber	3.8	4.6	5.3	4.0	4.1
Acid detergent lignin	0.6	0.7	0.8	0.6	0.6
Total ash	7.1	7.1	7.5	7.3	6.8
Particle size[4] (μm)					
2,500	3.8	4.1	5.6	3.9	3.7
1,250	28.4	26.5	31.9	27.6	28.9
630	36.9	37.0	34.8	36.7	36.1
315	21.7	21.7	17.9	21.8	21.8
160	9.0	10.2	9.1	9.5	9.3
80	0.3	0.3	0.5	0.4	0.3
GMD[5] ± GSD[6]	862 ± 2.01	840 ± 2.04	924 ± 2.08	851 ± 2.03	859 ± 2.02

[1]The water holding capacity (± SD) and the swelling capacity (± SD) of the control diet, measured in triplicate, were 2.10 ± 0.172 mL/g DM and 2.80 ± 0.298 mL/g DM, respectively.

[2]Sugar beet pulp.

[3]According to Fundación Española Desarrollo Nutrición Animal (2010).

[4]The percentage of particles bigger than 2,500 μm and smaller than 80 μm were negligible for all diets.

[5]Geometric mean diameter.

[6]GSD = Log normal SD.

(from Meckel's diverticulum to ileo-cecal junction), and the 2 ceca (from the ostium to the tip of the right and left ceca) was measured on a glass surface using a flexible tape with a precision of 1 mm. The length of the small intestine (**SI**) was determined by adding the length of the duodenum, jejunum, and ileum. Body length of the pullets, measured from the tip of the beak to the end of the longest phalanx, was also determined on extended birds. Finally, the length and diameter (in the middle point of the bone) of the tarsus were measured using a digital caliper. All length measurements were expressed in absolute (cm) and relative (cm/kg BW) terms.

Laboratory Analysis

Representative samples of the fiber sources and diets were ground in a laboratory mill (Retsch Model Z-I, Stuttgart, Germany) equipped with a 1-mm screen and analyzed for moisture by oven-drying (method 930.15), total ash by muffle furnace method (942.05), and nitrogen by Dumas (method 968.06) using a Leco analyzer (Model FP-528, Leco Corp., St. Joseph, MI) as indicated by AOAC International (2005). Gross energy was determined using an adiabatic bomb calorimeter (model 1356, Parr Instrument Company, Moline, IL). Neutral detergent fiber (**NDF**), acid detergent fiber, and acid detergent lignin were determined as described by Van Soest et al. (1991) and expressed on an ash-free basis. Also, the total dietary fiber (**DF**) and the insoluble fraction of DF of the fiber sources were analyzed (methods 985.29 and 991.43) as proposed by AOAC International (2005). The soluble fraction of DF was calculated by difference between total and insoluble DF. The water-holding capacity (**WHC**, mL/g DM), swelling capacity (**SWC**, mL/g DM), and buffer properties of the fiber sources were determined as indicated by Jiménez-Moreno et al. (2009b). The particle size distribution and mean particle size of the fiber sources and diets, expressed as geometric mean diameter (**GMD**), were determined in 100-g samples using a shaker (Retsch, Stuttgart, Germany) provided with 8 sieves ranging in mesh from 5,000 to 40 μm, as described by the ASAE (1995). All the analyses were conducted in duplicate, except for buffer properties and GMD determinations, which were conducted in triplicate.

Table 4. Chemical analyses (% as fed basis, unless otherwise indicated) and particle size distribution of the grower diets (5 to 10 wk of age).

	Control diet[1]	Straw (4%)	Straw (4%)	SBP[2] (2%)	SBP (2%)
Calculated chemical analysis[3]					
AME_n (kcal/kg)	2,820	2,767	2,712	2,783	2,743
Digestible amino acids					
Lys	0.84	0.81	0.80	0.82	0.81
Met	0.41	0.40	0.39	0.40	0.40
Met+cys	0.68	0.66	0.65	0.66	0.65
Thr	0.58	0.56	0.55	0.57	0.56
Trp	0.19	0.19	0.19	0.19	0.19
Ether extract	3.7	3.6	3.6	3.6	3.5
Crude fiber	3.6	4.2	4.8	3.9	4.2
Calcium	0.93	0.92	0.90	0.93	0.93
Phosphorus	0.66	0.65	0.64	0.65	0.64
Digestible phosphorus	0.34	0.33	0.33	0.33	0.33
Determined chemical analysis					
DM	90.8	90.2	91.4	88.9	90.1
Gross energy (kcal/kg)	4,026	3,956	4,070	4,004	4,048
CP	18.4	17.2	18.2	17.9	17.9
Neutral detergent fiber	10.7	11.7	13.6	11.1	11.4
Acid detergent fiber	4.1	4.5	5.6	4.1	4.3
Acid detergent lignin	0.9	1.0	1.3	1.0	0.9
Total ash	5.2	5.2	5.5	5.1	5.1
Particle size[4] (μm)					
2,500	7.6	4.4	3.8	3.3	2.7
1,250	40.6	42.4	38.2	37.2	31.3
630	31.5	33.3	35.8	36.7	39.5
315	12.4	12.4	14.6	14.9	17.0
160	7.6	7.3	7.4	6.7	9.1
GMD[5] ± GSD[6]	1,080 ± 2.03	1,050 ± 1.97	995 ± 1.96	991 ± 1.93	899 ± 1.96

[1]The water holding capacity (± SD) and the swelling capacity (± SD) of the control diet, measured in triplicate, were 2.03 ± 0.102 mL/g DM and 2.93 ± 0.111 mL/g DM, respectively.

[2]Sugar beet pulp.

[3]According to Fundación Española Desarrollo Nutrición Animal (2010).

[4]The percentage of particles bigger than 2,500 μm and smaller than 160 μm were negligible for all diets.

[5]Geometric mean diameter.

[6]GSD = Log normal SD.

Statistical Analysis

Data were analyzed as a completely randomized design using the GLM procedure of SAS (SAS Institute, 1990) as reported by Beccaccia et al. (2015). Briefly, main effects (fiber source and level of inclusion of fiber) and the interactions were studied for the 4 treatments arranged as a 2 × 2 factorial. In addition, the Dunnett test was used to compare data for all traits between pullets fed the control diet and pullets fed each of the other treatments. Differences were considered significant at $P < 0.05$ and tendencies at $0.10 < P < 0.05$. Results in tables are presented as means.

RESULTS

The straw and the SBP contained by analyses 2.8 and 9.2% CP and 69.9 and 31.7% NDF, and had a GMD of 602 and 835 μm, respectively (Table 1). The NDF of the diets increased as the level of fiber increased (Tables 3 to 5). The GMD was similar for all the diets that included a fiber source and slightly lower than for that of the control diets in the starter, grower, and developer phases (average of 984, 869, and 954 for the fiber-containing diets vs. 1,080, 870, and 1,046 for the control diets, respectively).

Growth Performance

Mortality was 2.5% and not related to treatment (data not shown). Most of the mortality (96%) occurred during the first week of the experiment. No interactions between main effects (fiber source and level of fiber) were detected at any age. From hatch to 17 wk of age, the inclusion of 4% SBP at the expense of the whole diet, affected negatively FCR ($P < 0.001$) as well as ADG and EI ($P < 0.05$) (Table 6). Also, the inclusion of 4% straw, but not of 2% straw, reduced FCR ($P < 0.01$) and EI ($P < 0.05$). Straw inclusion, however, improved ADG ($P < 0.05$) and ECR ($P < 0.01$) as compared with SBP inclusion. An increase in the fiber content of the diet from 2 to 4% tended to reduce EI ($P = 0.059$) and reduced FCR ($P < 0.05$). Most of the negative effects of 4% SBP inclusion were observed during the last part of the rearing period. In fact, from 0 to 5 wk of age, none of the variables studied was affected by the inclusion of fiber in the diet. Moreover, ECR tended to improve with the inclusion of straw ($P = 0.052$) as compared with the inclusion of SBP.

Table 5. Chemical analyses (% as fed basis, unless otherwise indicated) and particle size distribution of the developer diets (10 to 17 wk of age).

	Control diet[1]	Straw (2%)	Straw (4%)	SBP[2] (2%)	SBP (4%)
Calculated chemical analysis[3]					
AME_n (kcal/kg)	2,790	2,741	2,687	2,754	2,718
Digestible amino acids					
Lys	0.67	0.66	0.64	0.66	0.65
Met	0.30	0.30	0.29	0.30	0.29
Met+cys	0.55	0.54	0.52	0.54	0.52
Thr	0.51	0.50	0.49	0.50	0.49
Trp	0.17	0.16	0.16	0.16	0.16
Ether extract	3.2	3.2	3.1	3.1	3.1
Crude fiber	3.9	4.5	5.1	4.2	4.5
Calcium	0.91	0.89	0.88	0.91	0.91
Phosphorus	0.59	0.58	0.57	0.58	0.57
Digestible phosphorus	0.28	0.27	0.27	0.27	0.27
Determined chemical analysis					
DM	93.1	92.8	91.7	91.4	91.9
Gross energy (kcal/kg)	3,964	3,961	3,957	3,899	3,971
CP	17.6	16.8	16.7	17.2	17.1
Neutral detergent fiber	14.3	14.9	17.3	14.5	15.2
Acid detergent fiber	4.6	5.0	5.9	4.7	4.9
Acid detergent lignin	1.1	1.0	1.0	0.9	1.0
Total ash	6.7	7.0	6.7	7.5	6.6
Particle size[4] (μm)					
2,500	10.0	11.1	10.8	10.2	9.8
1,250	36.6	29.3	29.6	30.1	29.9
630	29.5	30.5	30.9	31.3	31.7
315	14.9	17.3	16.8	17.5	17.3
160	8.6	11.0	11.0	10.4	10.6
80	0.3	0.7	0.9	0.4	0.6
GMD[5] ± GSD[6]	1,046 ± 2.15	953 ± 2.26	951 ± 2.26	960 ± 2.21	949 ± 2.21

[1]The water holding capacity (± SD) and the swelling capacity (± SD) of the control diet, measured in triplicate, were 2.10 ± 0.204 mL/g DM and 3.16 ± 0.149 mL/g DM, respectively.

[2]Sugar beet pulp.

[3]According to Fundación Española Desarrollo Nutrición Animal (2010).

[4]The percentage of particles bigger than 2,500 μm and smaller than 80 μm were negligible for all diets.

[5]Geometric mean diameter.

[6]GSD = Log normal SD.

From 5 to 10 wk of age, ADFI was lower ($P < 0.01$) in pullets fed the control or the SBP diets than in pullets fed the 4% straw diets, with pullets fed 2% straw being intermediate. In this period, pullet growth responded with higher ADFI and ADG ($P < 0.001$) and EI ($P < 0.01$), and better ECR ($P < 0.05$) to the inclusion of straw as compared to the inclusion of SBP. In fact, pullets fed the 4% SBP diets showed lower ADG ($P < 0.01$), FCR ($P < 0.01$), and EI ($P < 0.05$) than pullets fed the control diet. Body weight uniformity was not affected by diet at any age (Table 7).

Gastrointestinal Tract Traits and Body Measurements

No interactions between main effects were detected for any of the traits studied and therefore, only main effects are discussed. At 5 wk of age, the inclusion of fiber did not affect the relative weight of any of the organs of the GIT (Table 8). However, in absolute terms the gizzard tended to be heavier in pullets fed straw than in pullets fed SBP ($P = 0.056$) (Table 9). Moreover, an increase in fiber from 2% to 4% tended to increase the relative weight (5.22 vs. 5.56%; $P = 0.056$) of the gizzard. Also at this age, the relative length of the SI was higher in pullets fed SBP than in pullets fed straw (296 vs. 279 cm/kg BW; $P = 0.051$) but cecum length was not affected (Table 10). At 10 wk of age, pullets fed the control diet had lighter gizzards in relative and absolute terms ($P < 0.01$) than pullets fed the 4% straw diets. Pullets fed SBP had greater relative weight of the GIT ($P < 0.01$) than pullets fed straw. Also at this age, gizzard relative weight increased as the level of fiber increased ($P < 0.01$). Moreover, the relative length of the SI was higher ($P < 0.05$) in pullets fed SBP than in pullet fed straw but no differences were detected for the cecum.

At 5 and 10 wk of age, the relative length of the pullets ($P = 0.058$ and $P < 0.05$, respectively) and of the tarsus ($P = 0.079$ and $P < 0.05$, respectively) were higher with SBP than with straw. Dietary treatment, however, had little effect on GIT development at 17 wk of age. Opposite to data reported in relative terms, the absolute length was higher in pullets fed straw than in pullets fed SBP, with differences tending to be significant at 5 wk of age ($P = 0.054$) (data not shown).

Table 6. Influence of source (SOU) and level (LEV) of fiber in the diet on growth performance, energy intake[1] (EI, kcal AME_n/d), and energy conversion ratio (ECR, kcal AME_n/g ADG) of the pullets from hatching to 17 wk of age.

		Straw		SBP[2]		Fiber source		Inclusion level			Probability[4]	
	Control	2%	4%	2%	4%	Straw	SBP	2%	4%	Sd[3]	SOU	LEV
0 to 5 week												
ADFI	19.6	20.1	20.3	20.1	20.2	20.2	20.2	20.1	20.2	0.72	0.827	0.580
ADG	8.55	8.78	8.79	8.75	8.57	8.79	8.66	8.77	8.68	0.350	0.138	0.305
FCR[5]	2.29	2.29	2.31	2.30	2.36	2.30	2.33	2.30	2.33	0.083	0.266	0.171
EI	58.1	58.4	57.6	58.7	58.2	58.0	58.5	58.6	57.9	2.09	0.447	0.285
ECR[6]	6.80	6.65	6.55	6.71	6.80	6.60	6.76	6.68	6.68	0.242	0.052	0.916
5 to 10 week												
ADFI[7]	49.7	50.7	51.2	49.7	49.5	50.9	49.6	50.2	50.4	1.01	<.001	0.645
ADG[8]	15.1	15.2	15.2	14.8	14.5	15.2	14.6	15.0	14.8	0.38	<.001	0.190
FCR[8]	3.30	3.34	3.37	3.36	3.42	3.36	3.39	3.35	3.40	0.080	0.143	0.075
EI[9]	140.1	140.4	138.8	138.3	136.1	139.6	137.2	139.3	137.5	2.80	0.007	0.031
ECR	9.31	9.25	9.15	9.35	9.41	9.20	9.38	9.30	9.28	0.249	0.021	0.752
10 to 17 week												
ADFI	68.0	67.7	68.0	67.7	68.0	67.9	67.9	67.7	68.0	2.21	0.995	0.644
ADG[10]	12.1	11.6	11.5	11.6	11.5	11.5	11.5	11.6	11.5	0.61	0.984	0.644
FCR[11]	5.61	5.86	5.92	5.85	5.93	5.89	5.89	5.85	5.93	0.211	0.484	0.938
EI[12]	186.9	182.1	179.6	183.5	181.7	180.9	182.6	182.8	180.7	5.95	0.397	0.286
ECR	15.4	15.8	15.6	15.9	15.8	15.7	15.9	15.8	15.7	0.57	0.511	0.535
0 to 17 week												
ADFI	48.9	49.3	49.6	49.0	49.1	49.4	49.0	49.1	49.3	0.95	0.209	0.490
ADG[13]	12.0	11.8	11.8	11.7	11.5	11.8	11.6	11.8	11.7	0.31	0.042	0.231
FCR[14]	4.09	4.16	4.20	4.18	4.27	4.18	4.22	4.17	4.23	0.072	0.128	0.016
EI[15]	136.8	134.9	133.1	134.9	133.4	134.0	134.2	134.9	133.3	2.57	0.860	0.059
ECR	11.4	11.4	11.3	11.5	11.6	11.3	11.6	11.5	11.4	0.20	0.004	0.550

[1]Energy intake calculated from the AME_n of the diets presented in Tables 3 to 5.

[2]Sugar beet pulp.

[3]Standard deviation (n = 10 for each treatment and n = 20 for main effects).

[4]The interaction between source and level of fiber inclusion was not significant ($P > 0.10$).

[5]Feed conversion ratio.

[6]Contrast of control vs. 4% straw ($P = 0.089$).

[7]Contrast of control vs. 2% straw ($P = 0.095$) and control vs. 4% straw ($P = 0.005$).

[8]Contrast of control vs. 4% SBP ($P = 0.005$).

[9]Contrast of control vs. 4% SBP ($P = 0.010$).

[10]Contrast of control vs. 4% straw ($P = 0.087$) and control vs. 4% SBP ($P = 0.081$).

[11]Contrast of control vs. 2% straw ($P = 0.035$), control vs. 4% straw ($P = 0.006$), control vs. 2% SBP ($P = 0.036$), and control vs. 4% SBP ($P = 0.012$).

[12]Contrast of control vs. 4% straw ($P = 0.030$).

[13]Contrast of control vs. 4% SBP ($P = 0.008$)

[14]Contrast of control vs. 4% straw ($P = 0.004$), control vs. 2% SBP ($P = 0.025$), and control vs. 4% SBP ($P < 0.001$).

[15]Contrast of control vs. 4% straw ($P = 0.010$) and control vs. 4% SBP ($P = 0.019$).

Table 7. Influence of source (SOU) and level (LEV) of fiber in the diet on BW uniformity[1] of the pullets.

		Straw		SBP[2]		Fiber source		Inclusion level			Probability[4]	
	Control	2%	4%	2%	4%	Straw	SBP	2%	4%	Sd[3]	SOU	LEV
5 week	8.02	9.33	8.88	8.64	9.07	9.11	8.85	8.99	8.97	1.569	0.618	0.982
10 week	8.37	8.99	7.99	9.08	8.83	8.49	8.96	9.04	8.41	1.543	0.373	0.233
17 week	7.26	8.36	7.83	8.68	8.68	8.09	8.68	8.52	8.25	1.731	0.301	0.638

[1]Evaluated as the CV (%) of BW (Peak et al., 2000).

[2]Sugar beet pulp.

[3]Standard deviation (n = 10 for each treatment and n = 20 for main effects).

[4]The interaction between source and level of fiber inclusion was not significant ($P > 0.10$).

DISCUSSION

The CP and NDF contents of the straw were slightly lower than values reported by García et al. (1996) for barley straw and Gidenne (2003) for wheat straw. For the SBP, the analyzed values of CP and NDF were lower than those reported by González-Alvarado et al. (2010) and Jiménez-Moreno et al. (2013b), although the differences were of little practical interest. The determined chemical analyses of the diets were similar to expected values, indicating that the diets were mixed correctly.

Table 8. Influence of source (SOU) and level (LEV) of fiber in the diet on the relative weight (% BW) of selected digestive organs of the pullets.

		Straw		SBP[1]		Fiber source		Inclusion level			Probability[3]	
	Control	2%	4%	2%	4%	Straw	SBP	2%	4%	Sd[2]	SOU	LEV
5 week												
BW	343	361	357	340	338	359	339	350	348			
GIT[4]	19.7	20.0	20.0	20.4	20.7	20.0	20.6	20.2	20.4	1.22	0.169	0.625
Liver	4.06	4.12	3.90	4.16	3.91	4.01	4.03	4.14	3.90	0.387	0.849	0.045
Proventriculus[5,6]	0.79	0.85	0.90	0.85	0.89	0.87	0.87	0.85	0.89	0.092	0.896	0.206
Gizzard[5]	5.08	5.27	5.52	5.17	5.60	5.39	5.38	5.22	5.56	0.531	0.957	0.056
10 week												
BW	874	901	899	868	837	900	852	884	868			
GIT	13.6	13.8	14.1	14.8	14.7	14.0	14.8	14.3	14.4	1.29	0.007	0.819
Liver[7]	2.67	2.50	2.41	2.63	2.53	2.46	2.58	2.56	2.47	0.250	0.142	0.288
Proventriculus	0.65	0.60	0.62	0.63	0.63	0.61	0.63	0.61	0.63	0.062	0.257	0.428
Gizzard[8]	4.21	4.33	4.70	4.31	4.60	4.51	4.45	4.32	4.65	0.316	0.584	0.004
17 week												
BW	1,512	1,500	1,502	1,507	1,452	1,501	1,479	1,503	1477			
GIT[9]	11.5	11.9	11.9	11.5	12.5	11.9	12.0	11.7	12.2	0.93	0.769	0.092
Liver	2.06	2.04	2.02	2.00	2.11	2.03	2.06	2.02	2.07	0.291	0.766	0.627
Proventriculus	0.55	0.51	0.55	0.52	0.54	0.53	0.53	0.51	0.54	0.058	0.936	0.084
Gizzard	3.60	3.80	3.98	3.74	3.91	3.89	3.82	3.77	3.94	0.400	0.643	0.192

[1]Sugar beet pulp.

[2]Standard deviation (n = 10 for each treatment and n = 20 for main effects).

[3]The interaction between source and level of fiber inclusion was not significant ($P > 0.10$).

[4]Full gastrointestinal tract including liver, pancreas, and spleen but not the crop and the esophagus.

[5]With contents.

[6]Contrast of control vs. 4% straw ($P = 0.039$), and control vs. 4% SBP ($P = 0.077$).

[7]Contrast of control vs. 4% straw ($P = 0.091$).

[8]Contrast of control vs. 4% straw ($P = 0.005$) and control vs. 4% SBP ($P = 0.029$).

[9]Contrast of control vs. 4% SBP ($P = 0.083$).

Growth Performance

Body weight at 17 wk of age is one of the most important factors affecting egg production and egg size at the initiation of the egg cycle (Summers et al., 1987). Moreover, FCR from 0 to 17 wk of age is significantly correlated with pullet cost. For the entire experimental period, pullets fed the control diets showed 1.7 and 3.3% higher ADG and 2.7 and 3.7% better FCR than pullets fed the 4% straw- or 4% SBP-containing diets. From hatching to 5 wk of age, however, the inclusion of 2 or 4% of the fiber sources at the expense (wt:wt) of the whole diet did not affect ADG or FCR. Guzmán et al. (2015) reported that pullets fed diets containing 2% straw or SBP from hatching to 5 wk of age, had 3.7% greater ADG in both cases than pullets fed the control diet, consistent with the results reported herein. González-Alvarado et al. (2010) reported that FCR improved with the inclusion of 3% SBP in the diet in broilers from 1 to 10 d of age but not from 10 to 42 d of age. The maximal growth of all organs and segments of the GIT in broilers is reached before d 9 post-hatching (González-Alvarado et al., 2008). Consequently, during the first stages of life, dietary fiber might stimulate the development of the upper part of the GIT, benefiting bird performance. Sugar beet pulp, however, is rich in pectins, a fiber fraction with a high WHC and SWC, that increases the bulk and the viscosity of the digesta (Bach Knudsen, 2001), reduces the rate of digesta passage along the distal part of the GIT, and decreases feed intake in older broilers (Jiménez-Moreno et al., 2009a; González-Alvarado et al., 2010). The authors, however, have not found any published research on the effects of the inclusion of additional fiber in the diet on performance of pullets for the entire rearing phase.

Poultry eat to satisfy their energy requirements, and therefore, EI should be similar for all diets, irrespective of their fiber content. In this respect, Leeson et al. (1996) reported that broilers from 0 to 49 d of age adapted feed intake to maintain EI, when the diet was diluted with up to 3.75% OH. The influence of additional fiber on EI, ECR, and FCR, however, is a subject of debate. In the current research, ADFI from 0 to 17 wk of age increased as the level of fiber in the diet increased, although the differences were not significant. However, pullets fed the control diet had 2.5 and 2.7% higher EI than pullets fed the 4% SBP- or straw-containing diet, respectively. The results indicate that from 0 to 17 wk of age, pullets were not able to consume enough feed to regulate precisely EI to meet their needs, and that ADG and FCR were lower when fed 4% straw or SBP. Jiménez-Moreno et al. (2015) reported also 5.0 and 4.4% higher EI in broilers when fed a control diet with only 3.6% NDF than when fed diets with 5.0% OH or SFH that contained 7.1 and 7.2% NDF, respectively. Additional fiber increases the bulk of the feed and satiates faster bird appetite, which in turn might result in pullets unable to regulate EI. Consequently,

Table 9. Influence of source (SOU) and level (LEV) of fiber in the diet on the absolute full organ weight (g) and digesta content (expressed as% to full organ weight) of the proventriculus and the gizzard and pH of the gizzard.

			Straw		SBP[1]		Fiber source		Inclusion level			Probability[3]	
		Control	2%	4%	2%	4%	Straw	SBP	2%	4%	Sd[2]	SOU	LEV
5 week													
Proventriculus	Weight	2.95	2.94	2.99	3.13	3.08	2.97	3.10	3.04	3.03	0.363	0.256	0.975
	Content	6.21	4.84	5.06	6.12	5.75	4.95	5.94	5.48	5.40	2.926	0.270	0.932
Gizzard	Weight[4]	17.3	19.0	19.6	17.5	18.9	19.3	18.2	18.2	19.2	1.76	0.056	0.082
	Content	36.8	33.0	35.6	33.8	35.1	34.3	34.4	33.4	35.4	4.47	0.946	0.152
10 week													
Proventriculus	Weight	5.64	5.39	5.58	5.43	5.29	5.49	5.36	5.41	5.44	0.528	0.391	0.851
	Content	9.04	5.50	7.97	9.74	7.53	6.73	8.64	7.62	7.75	4.124	0.133	0.916
Gizzard	Weight[5]	36.6	38.9	42.1	37.4	38.3	40.5	37.8	38.2	40.2	3.21	0.016	0.062
	Content	29.2	29.8	30.5	29.9	28.7	30.1	29.3	29.8	29.6	4.43	0.553	0.873
	pH[6]	2.94	2.60	2.43	2.84	2.60	2.51	2.72	2.72	2.51	0.481	0.188	0.199
17 week													
Proventriculus	Weight	8.28	7.63	8.22	7.88	7.80	7.92	7.84	7.76	8.01	1.107	0.805	0.440
	Content	8.09	6.02	7.31	8.77	7.18	6.67	7.97	7.39	7.25	3.537	0.282	0.902
Gizzard	Weight	54.1	58.3	59.7	56.4	56.8	59.0	56.6	57.4	58.3	6.65	0.291	0.694
	Content[7]	27.5	30.8	28.7	28.8	29.5	29.6	29.1	29.8	29.1	3.52	0.524	0.510

[1]Sugar beet pulp.
[2]Standard deviation (n = 10 for each treatment and n = 20 for main effects).
[3]The interaction between source and level of fiber inclusion was not significant ($P > 0.05$).
[4]Contrast of control vs. 4% straw ($P = 0.025$).
[5]Contrast of control vs. 4% straw ($P = 0.002$).
[6]Contrast of control vs. 4% straw ($P = 0.066$).
[7]Contrast of control vs. 2% straw ($P = 0.040$).

unless nutrient digestibility is improved, FCR might be reduced when extra amounts of fiber are included in the diet. In this respect, González-Alvarado et al. (2010) reported 6.3 and 3.8% better FCR in broilers from 1 to 42 d of age when fed 3% OH or SBP than when fed the control diet. In the current research, the level of NDF of the control diet was higher than that used in most experiments conducted with broilers. For example, the basal broiler diet used by González-Alvarado et al. (2010) contained 5.3% NDF in the starter period (1 to 25 d of age) and 5.7% NDF in the finisher period (26 to 42 d of age) whereas in the current research, the control pullet diet had 9.4% NDF in the starter period and 14.3% NDF in the finisher period. We hypothesize that the beneficial effects of including additional fiber in the diet could be more evident in broilers than in pullets because of the lower NDF level of their diets and their higher appetite and rate of growth. Consequently, less effect of additional fiber on pullet growth should be expected in the current research because the need for fiber of the birds was already satisfied when fed the control diet (Mateos et al., 2012).

From hatching to 17 wk of age, ADG was better for pullets fed straw than for pullets fed SBP. Guzmán et al. (2015) observed that from 0 to 5 wk of age, pullets fed 2 and 4% SFH, an insoluble fiber source, had as an average 2.8% greater ADG than pullets fed 2 and 4% SBP, a soluble fiber source, in agreement with the results reported herein. In broilers from 1 to 42 d of age, González-Alvarado et al. (2010) reported also 6.7% greater ADG when fed a diet with 3% OH than when fed a diet with 3% SBP. The differences in ADG and also in ECR observed at 17 wk of age between birds fed straw and birds fed SBP might be related to the distinct physicochemical properties of these 2 fiber sources. Acid detergent fiber and lignin contents are higher for the straw than for the SBP and therefore, straw particles will be more resistant to grinding and will be retained for longer in the gizzard than SBP particles. As a result, the gizzard will be heavier and the pH of the digesta lower with straw than with SBP (Bach Knudsen, 2001; Jiménez-Moreno et al., 2013b). On the other hand, WHC and SWC are higher in SBP than in straw because of differences in pectin content (Bach Knudsen, 2014). Also, the soluble fraction of SBP might encapsulate part of the phospholipids and bile acids present in the digesta (Story and Kritchersky, 1982) reducing fat digestibility (Forman and Schneeman, 1980). Moreover, the fiber fraction of the diet modifies the environmental conditions within the GIT, which in turn might interfere with the digestion and absorption processes and affect the growth and profile of the existing microbiota (Kalmendal et al., 2011; Mateos et al., 2012; Bach Knudsen, 2014). Consequently, type and level of fiber might affect in different ways GIT environment, nutrient digestibility, and pullet growth.

The available information suggests that the inclusion of moderate amounts of fiber in commercial diets for pullets had little effect on growth during the first period of life but that negative effects might occur as the bird ages, especially when a high level of a soluble fiber source, such as SBP, is used. In this respect, no recommendations on the level and type of fiber of diets for pullets are available from the National

Table 10. Influence of source (SOU) and level (LEV) of fiber source in the diet on the relative length (cm/kg BW[1]) of the organs of the gastrointestinal tract, pullets[2], and the length and diameter[3] of the tarsus.

		Straw		SBP[4]		Fiber source		Inclusion level			Probability[6]	
	Control	2%	4%	2%	4%	Straw	SBP	2%	4%	Sd[5]	SOU	LEV
5 week												
Duodenum	51.7	48.3	49.3	52.3	53.0	48.8	52.6	50.3	51.1	5.07	0.032	0.627
Jejunum	131	124	127	129	136	125	132	126	131	12.4	0.088	0.233
Ileum	109	104	105	109	113	105	111	106	109	10.4	0.064	0.350
Small intestine	292	276	281	290	302	279	296	283	292	26.2	0.051	0.306
Cecum	54.3	53.8	51.9	55.4	56.4	52.8	55.9	54.6	54.1	6.28	0.150	0.821
Pullet	115	111	112	117	114	111	116	114	113	7.4	0.058	0.636
Tarsus	18.1	17.5	17.9	18.7	18.1	17.7	18.4	18.1	18.0	1.22	0.079	0.774
Tarsus diameter	1.87	1.79	1.82	1.88	1.85	1.81	1.86	1.83	1.84	0.135	0.172	0.916
10 week												
Duodenum	23.3	22.2	21.1	23.5	24.0	21.7	23.7	22.9	22.5	2.22	0.008	0.660
Jejunum	65.2	61.1	61.6	65.7	64.6	61.3	65.2	63.4	63.1	4.73	0.023	0.829
Ileum	52.2	50.3	50.2	53.4	51.5	50.2	52.5	51.9	50.8	5.45	0.216	0.563
Small intestine	141	134	133	143	140	133	141	138	136	10.1	0.021	0.615
Cecum	28.0	27.2	25.8	28.1	27.1	26.5	27.6	27.7	26.5	2.74	0.222	0.191
Pullet	67.0	64.6	65.8	67.7	68.8	65.2	68.2	66.2	67.3	2.82	0.002	0.243
Tarsus	8.43	8.07	8.18	8.45	8.58	8.13	8.52	8.26	8.38	0.519	0.028	0.485
Tarsus diameter	0.94	0.94	0.94	0.97	0.98	0.94	0.97	0.95	0.96	0.061	0.112	0.910
17 week												
Duodenum	14.4	14.4	14.7	14.4	15.2	14.6	14.8	14.4	14.9	1.32	0.602	0.240
Jejunum	39.3	39.7	39.5	39.4	40.7	39.6	40.0	39.6	40.1	3.62	0.698	0.662
Ileum	33.0	33.9	34.1	33.5	34.6	34.0	34.1	33.7	34.3	2.95	0.954	0.524
Small intestine	86.7	88.1	88.2	87.3	90.4	88.2	88.9	87.7	89.3	7.31	0.759	0.491
Cecum	11.1	11.2	11.2	11.1	11.5	11.2	11.3	11.1	11.3	0.82	0.720	0.456
Pullet	43.4	43.3	43.0	43.4	44.7	43.2	44.0	43.4	43.8	3.26	0.371	0.635
Tarsus	5.05	5.08	5.20	5.19	5.33	5.14	5.26	5.14	5.26	0.531	0.528	0.500
Tarsus diameter	0.61	0.59	0.63	0.62	0.63	0.61	0.62	0.61	0.63	0.059	0.591	0.301

[1]BW are shown in table 8.

[2]Measured from the tip of the beak to the end of the longest phalanx.

[3]Measured with a caliper above the spur.

[4]Sugar beet pulp

[5]Standard deviation (n = 10 for each treatment and n = 20 for main effects).

[6]The interaction between source and level of fiber inclusion was not significant ($P > 0.05$).

Research Council (1994) or from the main companies involved in genetic development of laying hens (e.g., Lohmann, 2013; Hy-Line International, 2015). However, Fundación Española Desarrollo Nutrición Animal (2008) recommends a minimum of CF of 3% in starter (0 to 5 wk) and 4% in finisher (10 to 17 wk) diets for pullets, values that are consistent with the results of the current research.

Gastrointestinal Tract Traits and Body Measurements

The relative weight of the full GIT, proventriculus, and gizzard, and of the liver, and the relative length of the different segments of the SI, decreased with age, results that agree with data of Ravindran et al. (2006), Gracia et al. (2009), and Jiménez-Moreno et al. (2010) and are consistent with the allometric growth rate of these organs and tissues in the chicken (Zuidhof, 2005).

The gizzard was heavier at all ages in pullets fed the 4% fiber-containing diets than in pullets fed the control diet. In fact, the differences were significant at 10 wk, an age at which the gizzard was 10.4 and 8.5% heavier in pullets fed 4% straw or 4% SBP than in pullets fed the control diet. Moreover, gizzard weight increased when the fiber level was increased from 2 to 4%, with differences being significant at 5 and 10 wk of age. González-Alvarado et al. (2007) suggested that the fiber fraction of the diet is retained for longer in the gizzard. An increase in retention time leads to an increase in size of the muscular walls and of this organ (Jiménez-Moreno et al., 2009a). In this respect, González-Alvarado et al. (2010) reported 45 and 31% heavier gizzards in 42-day-old broilers fed 3% OH or 3% SBP than in broilers fed the control diet. Similarly, Hetland et al. (2003) observed that the gizzard was 21% heavier in 33-day-old broilers fed 10% OH than in broilers fed the control diet. All this information suggests that insoluble fiber impacts more GIT development in broilers than in pullets, a phenomenon that might be related to the lower fiber content of the broiler diets but also to differences in feed intake and rate of feed passage between the 2 chicken lines.

In the current research, the relative weight of the GIT was greater in pullets fed SBP than in pullets fed straw, although the differences were significant only at 10 wk of age. These differences in relative weight of the GIT might be related to the distinct physicochemical characteristics of the fiber sources used. Jiménez-Moreno et al. (2013b) reported also heavier GIT in broilers fed SBP than in broilers fed OH. Similarly, Jørgensen et al.

(1996) observed heavier GIT in broilers fed pea hulls, a high pectin fiber source, than in broilers fed oat bran, a more insoluble fiber source.

The relative weight of the gizzard was similar for pullets fed straw than for pullets fed SBP. In contrast, Jiménez-Moreno et al. (2013b) observed heavier gizzards in broilers fed OH than in broilers fed SBP. The lower BW of pullets fed SBP than of pullets fed straw might have distorted the results when comparing data based on relative rather than on absolute weights. In this respect, in absolute terms, the gizzard was heavier in pullets fed straw than in pullets fed SBP at all ages, with differences being significant at 5 and 10 wk of age. Consequently, the data on the effects of fiber source on GIT development might be taken with caution. The digesta content of the gizzard was not affected by fiber inclusion at any age and therefore, the higher gizzard weight in pullets fed straw than in pullets fed SBP might be due to a greater development of the muscular layer of this organ, a consequence of the different physicochemical properties of the 2 fiber sources.

At 10 wk of age, the inclusion of 4% straw reduced gizzard pH by 17.3% as compared with that of pullets fed the control diet. Jiménez-Moreno et al. (2010) reported also a 19.7% reduction in gizzard pH in 21-day-old broilers with the inclusion of 3% OH in the diet. Insoluble fiber sources, such as straw or OH, are retained for longer in the gizzard, leading to a higher HCl production (Duke, 1986; Hetland et al., 2005; Jiménez-Moreno et al., 2013b). A low pH in the gizzard increases pepsin activity, mineral salts solubility, and nutrient digestibility (Rogel et al., 1987; Gabriel et al., 2003; Jiménez-Moreno et al. 2009c), effects that might favor bird performance.

The relative length of the SI was higher in pullets fed SBP than in pullets fed straw, with differences being significant at 10 wk of age, in agreement with data of Jiménez-Moreno et al. (2013a) who reported longer relative length of the SI in broilers fed SBP than in broilers fed OH. However, when the length values were compared in absolute terms, no differences were detected.

The relative length of the body and tarsus of the pullets were higher in pullets fed SBP than in pullets fed straw with differences being significant at 5 and 10 wk of age. The authors have not found in the literature any research on the effects of type of fiber on these traits to compare with the results reported herein. An increase in body and tarsus length suggests a better bone development (Cleasby et al., 2011) of the pullet which might be of benefit for future egg production (Senar and Pascual, 1997; Mendes et al., 2008). Opposite to these findings, the absolute length of the body and tarsus were higher for pullets fed straw than for pullets fed SBP. Consequently, data on the effects of fiber inclusion in the diet on the relative length of the SI, body, and tarsus must be taken with caution.

In summary, the inclusion (wt:wt) of fiber in the diet did not affect pullet development from 0 to 5 wk of age. The inclusion of 2% straw, at the expense of the whole diet, might benefit the development of the GIT of the pullets without any adverse effect on growth performance. Sugar beet pulp inclusion, however, reduced pullet performance after 5 wk of age. Therefore, up to 10% NDF (equivalent to 3.5% CF in the current research) from 0 to 5 wk and up to 15% NDF (4.5% CF) from 10 to 17 wk of age can be included in pullet diets, provided that insoluble fiber sources are used.

REFERENCES

AOAC International. 2005. Official Methods of Analysis of the AOAC International. 18th ed. AOAC Int., Gaithersburg, MD.

ASAE. 1995. Standard S319.2: Method of determining and expressing fineness of feed material by sieving. Pages 461–462 in Agriculture Engineers Yearbook of Standards. Am. Soc. Agric. Eng., St. Joseph, MO.

Bach Knudsen, K. E. 2001. The nutritional significance of "dietary fiber" analysis. Anim. Feed Sci. Technol. 90:3–20.

Bach Knudsen, K. E. 2014. Nutritional and functional properties of fiber in swine diets. Pages 35–49 In: Proceedings of the Midwest Swine Nutrition Conference. Indianapolis, IN, Sept. 4, 2014.

Beccaccia, A., S. Calvet, A. Cerisuelo, P. Ferrer, P. García-Rebollar, and C. De Blas. 2015. Effects of nutrition on digestion efficiency and gaseous emissions from slurry in growing-finishing pigs. I. Influence of the inclusion of two levels of orange pulp and carob meal in isofibrous diets. Anim. Feed Sci. Technol. 208:158–169.

Boletín Oficial del Estado. 2007. Ley 32/2007 de 7 de Noviembre para el cuidado de los animales, en su explotación, transporte, experimentación y sacrificio. BOE 268:45914–45920.

Cleasby, I. R., T. Burke, J. Schroeder, and S. Nakagawa. 2011. Food supplements increase adult tarsus length, but not growth rate, in an island population of house sparrows (*Passer domesticus*). BMC Res. Notes. 4:431.

Duke, G. E. 1986. Alimentary canal: Secretions and digestion, special digestion functions and absorption. Pages 289–302 in Avian Physiology. P. D. Sturkie, ed. Springer-Verlag, New York, NY.

Forman, L. P., and B. O. Schneeman. 1980. Effects of dietary pectin and fat on the small intestinal contents and exocrine pancreas of rats. J. Nutr. 110:1992–1999.

Fundación Española Desarrollo Nutrición Animal. 2008. Necesidades Nutricionales para Avicultura: Pollos de Carne y Aves de Puesta. R. Lázaro, and G. G. Mateos, Ed. Fund. Esp. Desarro. Nutr. Anim., Madrid, Spain.

Fundación Española Desarrollo Nutrición Animal. 2010. Normas FEDNA para la Formulación de Piensos Compuestos. 3rd ed. De Blas, C., G. G Mateos, and P. G. Rebollar, Ed. Fund. Esp. Desarro. Nutr. Anim., Madrid, Spain.

Gabriel, I., S. Mallet, and M. Leconte. 2003. Differences in the digestive tract characteristics of broiler chickens fed on complete pelleted diet or on whole wheat added to pelleted protein concentrate. Br. Poult. Sci. 44:283–290.

García, J., M. J. Villamide, and J. C. de Blas. 1996. Energy, protein and fibre digestibility of sunflower hulls, olive leaves and NaOH-treated barley straw for rabbits. World Rabbit Sci. 4:205–209.

Gidenne, T. 2003. Fibres in rabbit feeding for digestive troubles prevention: respective role of low-digested and digestible fibre. Livest. Prod. Sci. 81:105–117.

González-Alvarado, J.M., E. Jiménez-Moreno, D. González-Sánchez, R. Lázaro, and G. G. Mateos. 2010. Effect of inclusion of oat hulls and sugar beet pulp in the diet on productive performance and digestive traits of broilers from 1 to 42 days of age. Anim. Feed Sci. Technol. 162:37–46.

González-Alvarado, J. M., E. Jiménez-Moreno, D. G. Valencia, R. Lázaro, and G. G. Mateos. 2008. Effects of fiber source and heat processing of the cereal on the development and pH of the gastrointestinal tract of broilers fed diets based on corn or rice. Poult. Sci. 87:1779–1795.

González-Alvarado, J. M., E. Jiménez-Moreno, R. Lázaro, and G. G. Mateos. 2007. Effect of type of cereal, heat processing of the cereal, and inclusion of fiber in the diet on productive performance and digestive traits of broilers. Poult. Sci. 86:1705–1715.

Gracia, M. I., R. Lázaro, M. A. Latorre, P. Medel, M. J. Araníbar, E. Jiménez-Moreno, and G. G. Mateos. 2009. Influence of enzyme supplementation of diets and cooking-flaking of maize on digestive traits and growth performance of broilers from 1 to 21 days of age. Anim. Feed Sci. Technol. 150:303–315.

Guzmán, P., B. Saldaña, H. A. Mandalawi, A. Pérez-Bonilla, R. Lázaro, and G. G. Mateos. 2015. Productive performance of brown-egg laying pullets from hatching to 5 weeks of age as affected by fiber inclusion, feed form, and energy concentration of the diet. Poult Sci. 94:249–261.

Hetland, H., B. Svihus, and Å. Krogdalhl. 2003. Effects of oat hulls and wood shaving on digestion in broilers and layers fed diets based on whole or ground wheat. Br. Poult. Sci. 44:275–282.

Hetland, H., B. Svihus, and M. Choct. 2005. Role of insoluble ffibre on gizzard activity in layers. World's Poult. Sci. J. 60:415–422.

Hy-Line International. 2015. Hy-Line Brown Commercial Layers, Management Guide. Hy-Line International, West Des Moines, IA

Incharoen, T. 2013. Histological adaptations of the gastrointestinal tract of broilers fed diets containing insoluble fiber from rice hull meal. Am. J. Anim. Vet. Sci. 8:79–88.

Janssen, W. M. M. A., and B. Carré. 1985. Influence of fiber on digestibility of broiler feeds. Pages 78–93 in Recent Advances in Animal Nutrition. D. J. A. Cole, and W. Haresign, Ed. Bulterworths, London, UK.

Jiménez-Moreno, E., A. de Coca-Sinova, J. M. González-Alvarado, and G. G. Mateos. 2015. Inclusion of insoluble fiber sources in mash or pellet diets for broilers. 1. Effects on growth performance and water intake. Poult. Sci. PS-15–04927 (In press).

Jiménez-Moreno, E., J. M. González-Alvarado, A. de Coca-Sinova, R. Lázaro, and G. G. Mateos. 2009b. Effects of source of fibre on the development and pH of the gastrointestinal tract of broilers. Anim. Feed Sci. Technol. 154:93–101.

Jiménez-Moreno, E., J. M. González-Alvarado, A. González-Serrano, R. Lázaro, and G. G. Mateos. 2009c. Effect of dietary fiber and fat on performance and digestive traits of broilers from 1 to 21 days of age. Poult. Sci. 88:2562–2574.

Jiménez-Moreno, E., J. M. González-Alvarado, D. González-Sánchez, R. Lázaro, and G. G. Mateos 2010. Effects of type and particle size of dietary fiber on growth performance and digestive traits of broilers from 1 to 21 days of age. Poult. Sci. 89: 2197–2212.

Jiménez-Moreno, E., J. M. González-Alvarado, R. Lázaro, and G. G. Mateos. 2009a. Effects of type of cereal, heat processing of the cereal, and fiber inclusion in the diet on gizzard pH and nutrient utilization in broilers at different ages. Poult. Sci. 88:1925–1933.

Jiménez-Moreno, E., M. Frikha, A. de Coca-Sinova, J. García, and G. G. Mateos. 2013a. Oat hulls and sugar beet pulp in diets for broilers 1. Effects on growth performance and nutrient digestibility. Anim. Feed Sci. Technol. 182:33–43.

Jiménez-Moreno, E., M. Frikha, A. de Coca-Sinova, R. Lázaro, and G. G. Mateos. 2013b. Oat hulls and sugar beet pulp in diets for broilers. 2. Effects on the development of the gastrointestinal tract and on the structure of the jejunal mucosa. Anim. Feed Sci. Technol. 182:44–52.

Jiménez-Moreno, E., S. Chamorro, M. Frikha, H. M. Safaa, R. Lázaro, and G. G. Mateos. 2011. Effects of increasing levels of pea hulls in the diet on productive performance, development of the gastrointestinal tract, and nutrient retention of broilers from one to eighteen days of age. Anim. Feed Sci. Technol. 168: 100–112.

Jørgensen, H., X. Zhao, K. E. B. Knudsen, and B. O. Eggum. 1996. The influence of dietary fibre source and level on the development of the gastrointestinal tract, digestibility and energy metabolism in broiler chickens. Br. J. Nutr. 75:379–395.

Kalmendal, R., K. Elwinger, L. Holm, and R. Tauson. 2011. High-fibre sunflower cake affects small intestinal digestion and health in broiler chickens. Br. Poult. Sci. 52:86–96.

Leeson, S., L. Caston, and J. D. Summers. 1996. Broiler response to diet energy. Poult. Sci. 75:529–535.

Lohmann. 2013. Management Guide for Lohmann Brown-Classic. Lohmann Tierzucht GmbH, Cuxhaven, Germany.

Mateos, G. G., E. Jiménez-Moreno, M. P. Serrano, and R. P. Lázaro. 2012. Poultry response to high levels of dietary fiber sources varying in physical and chemical characteristics. J. Appl. Poult. Res. 21:156–174.

Mendes, M., A. Pala, and E. Dincer. 2008. Body mass index slopes of growth and fat content under different feed restrictions in broiler chickens. Arch. Gefl. 72:41–45.

National Research Council. 1994. Nutrient Requirements of Poultry. Natl Academy Press. Washington D.C.

Peak, S. D., T. J. Walsh, C. E. Benton, and J. Brake. 2000. Effects of two planes of nutrition on performance and uniformity of four strains of broiler chicks. J. Appl. Poult. Res. 9: 185–194.

Pettersson, D., and A. Razdan. 1993. Effects of increasing levels of sugar-beet pulp in broiler chicken diets on nutrient digestion and serum lipids. Br. J. Nutr. 70:127–137.

Ravindran, V., Y. B. Wu, D. G. Thomas, and P. C. H. Morel. 2006. Influence of whole wheat feeding on the development of gastrointestinal tract and performance of broiler chickens. Aust. J. Agric. Res. 57:21–26.

Rogel, A. M., D. Balnave, W. L. Bryden, and E. F. Annison. 1987. Improvement of raw potato starch digestion in chickens by feeding oat hulls and other fibrous feedstuffs. Aust. J. Agric. Res. 38: 629–637.

SAS Institute. 1990. SAS STAT User's Guide. Version 6, 4th ed. SAS Inst. Inc., Cary, NC.

Sell, J. L. 1996. Physiological limitations and potential for improvement in gastrointestinal tract function of poultry. J. Appl. Poult. Res. 5:96–101.

Senar, J. E., and J. Pascual 1997. Keel and tarsus length may provide a good predictor of avian body size. Ardea 85:269–274.

Sklan, D., A. Smirnov, and I. Plavnik. 2003. The effect of dietary fibre on the small intestines and apparent digestion in the turkey. Br. Poult. Sci. 44:735–740.

Story, J., and D. Kritchevsky. 1982. Comparison of the binding of various bile acids and bile salts in vitro by several types of fiber. J. Nutr. 106:1292–1294.

Summers, J.D., S. Leeson, and D. Spratt, 1987. Rearing early maturing pullets. Poult. Sci. 66:1750–1757.

Svihus, B. 2011. The gizzard: function, influence of diet structure and effects on nutrient availability. World Poult. Sci. J. 67:207–224.

Uni, Z., Y. Noy, and D. Sklan. 1999. Posthatch development of small intestinal function in the poult. Poult. Sci. 78: 215–222.

Van Soest, P. J., J. B. Robertson, and A. Lewis. 1991. Methods for dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. J. Dairy Sci. 74: 3583–3597.

Zuidhof, M. J. 2005. Mathematical characterization of broiler carcass yield dynamics. Poult. Sci. 84:1108–1122.